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# Effects of Magnetic Fields on Hadronic Cascades

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## 1. Introduction

The Monte Carlo program CASIM[1] and its muon tracking code[2] have been modified to allow inclusion of magnetic fields. The increasing use of high-field superconducting magnets at Fermilab motivates this addition to the program.

A second feature of the program allows the user to study relatively small differences in the cascade development resulting from correspondingly small changes in the definition of the problem.

These two items are briefly discussed in turn along with an illustration from a realistic application.

2. Magnetic Fields

Since even in the absence of magnetic fields problems generally are treated quite approximately, the description of the fields as well as the algorithm determining its influence on particle trajectories may be rather crude. The description of the field, $\vec{B}$ (in kG) as a function of location will generally be user supplied using either an analytical model or a numerical approach.

In CASIM representative particles of the cascade are stepwise transported, pausing at each step to consult the geometry subroutine. If need be interaction probabilities, energy loss, etc. are adjusted and if multiple Coulomb scattering is included in the calculation (at the user's option) a new direction is determined. The treatment of the magnetic field is similar. From the Lorentz force the change in the x-direction cosine, $D_x$, due to an infintesimal step, ds, is readily seen to be

$$D_x' = D_x + e(D_yB_z - D_zB_y)ds/p$$

where p is the particle's momentum and e its charge, with obvious extensions for $D_y'$ and $D_z'$. Adjustments for finite step size are applied in the same way as for multiple scattering[1]. As long as the stepsize is kept reasonably small (one third, or less, of a collision length) no appreciable error should result from this.

3. Correlated Sampling and Synchronized Random Numbers

Frequently in the design of experiments or facilities it is of interest to explore the effects of relatively small changes on questions relating to cascade development. Examples are small changes in geometry, composition, magnetic field, incident energy, beam size, etc. Because of the statistical uncertainty inherent in the Monte Carlo method unreasonably long computer times may be required to study the effect of such small changes. However if the common parts of such problems are computed by calling on the same sequences of random numbers, then the error on the difference between these common parts disappears entirely (the coefficient of correlation being unity) and only the error associated with the distinct parts remains.[3]

For certain types of problems this may be accomplished by treating two or more cases simultaneously in the same computer run. For example, the energy deposition in several (homogeneous) targets of different dimensions was estimated by computing the cascade development in a target sufficiently large to contain them all. Whenever in the calculation a representative cascade particle is outside a given subtarget, this particle and its "progeny" no longer contribute to the energy deposition within that subtarget. (This example was actually run in the planning of a target heating experiment.[4]) This scheme has the added advantage of savings in computer time vis-a-vis running each case separately. A disadvantage is the extra coding (and storage) required.

For many problems simultaneous computation does not apply, e.g., changing the incident energy or the magnetic field. In other cases the extra coding required may be judged too laborious or a change may suggest itself after a computer run has already been made. The random number "coherence" may then be preserved in separate computer runs as long as the sequence of random numbers called upon every time an incident particle is introduced is exactly replicated. A practical way is to have two separate random number generators in the calculation; one serving to "seed" the other when a new incident particle is generated. Synchronized random numbers may also be useful in the debugging stages of a new problem.

By way of illustration, Fig. 1 shows momentum spectra of hadrons penetrating a large ($\sim$ 6m) iron block (muon spectrometer of Exp. 439) calculated without and with a magnetic field ($B_{max}$ = 18 kG). The plots show clearly the effect of the field even in the presence of sizable random errors.

I wish to thank M. Awschalom and P. Gollon for their comments.

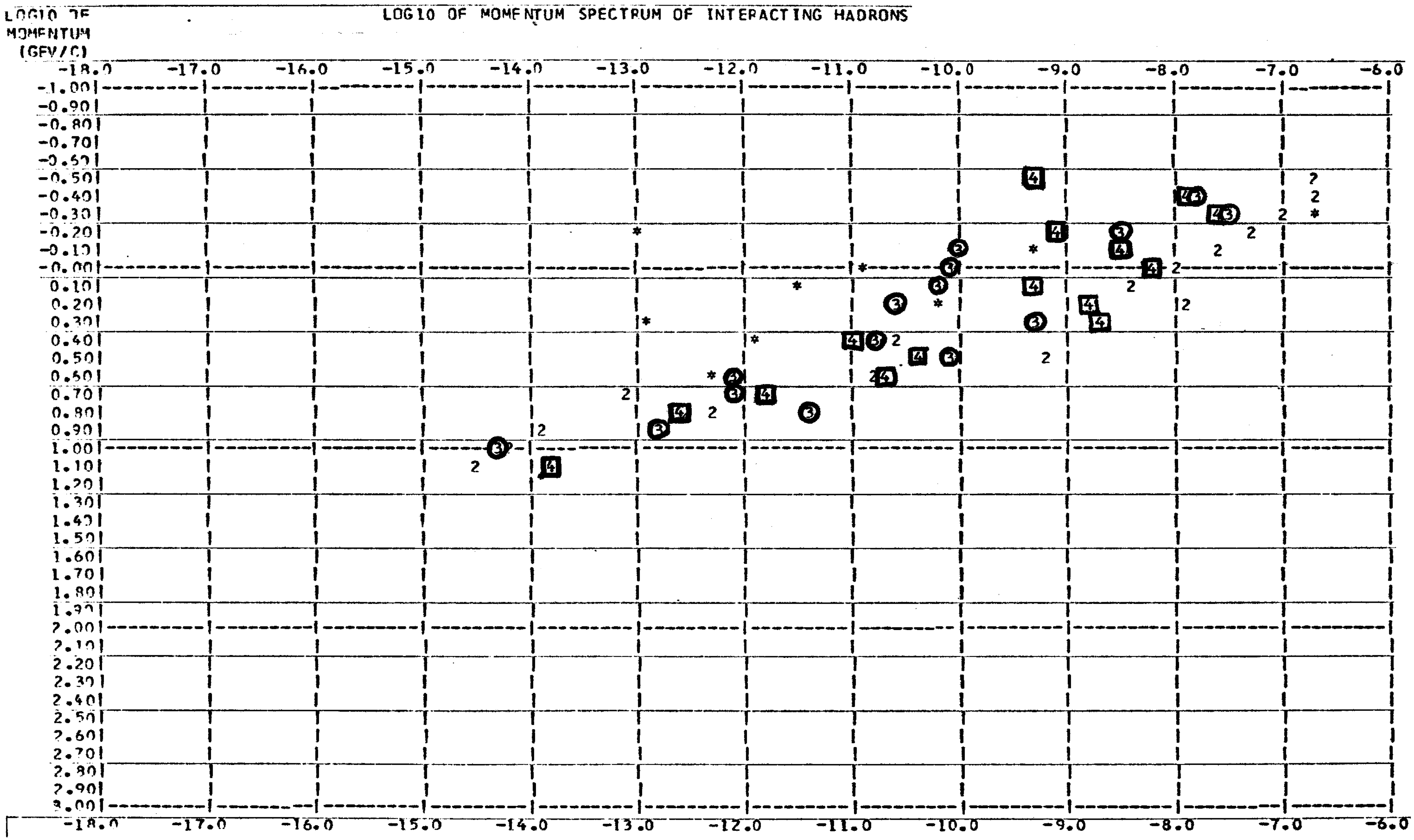
## References

1. A. Van Ginneken, "CASIM. Program to Simulate Transport of Hadronic Cascades in Bulk Matter", Fermilab-FN-272 (1975).
2. A. Van Ginneken, "Penetration of Prompt and Decay Muon Components of Hadronic Cascades through Thick Shields", Fermilab-TM-630 (1975).
3. U. Fano, L. V. Spencer and M. J. Berger, "Penetration and Diffusion of X Rays", Handbuch der Physik, S. Flugge, Ed., Vol. XXXVIII/2 p. 787 et seq. (1959).
4. M. Awschalom et al., Nucl. Inst. and Meth., 131, 235 (1975).

## Figure Captions

Fig. 1. Momentum spectra of hadrons penetrating a large (4.8 m long) iron shield integrated over the lateral region indicated in the legend (a) without magnetic field (b) with magnetic field present. The effect of the field can best be seen by comparing $\pi^+$ and $\pi^-$ spectra (denoted by symbols 3 and 4 in the plots).

PLOT OF LOG OF MOMENTUM SPECTRUM OF HADRONS ESCAPING BACKOF CONFIGURATION
X BOUNDARIES: 0.0 TO 60.00 Y BOUNDARIES: -60.00 TO 60.00 (IN CM)
EXCLUDING PREVIOUS X,Y REGION (EXCEPT FOR CENTRAL REGION)
UNITS OF PTCLES/CM2*INC.PTCLE




THE SYMBOLS *,2,3,4 REFER TO PROTONS,NEUTRONS,PI PLUS,PI MINUS
LOG10 OF MOMENTUM VALUES REFER TO AVERAGE OF EACH MOMENTUM BIN



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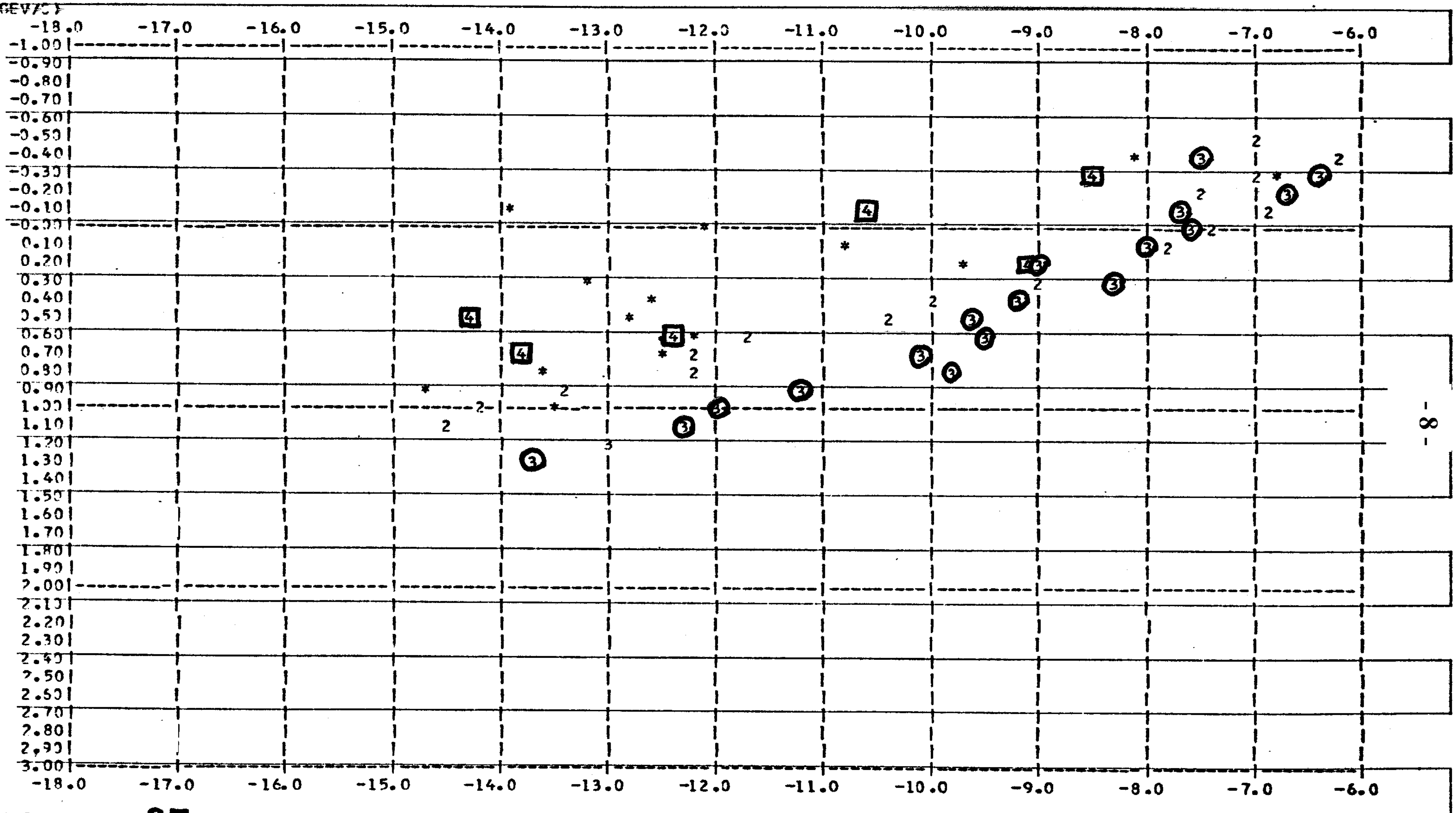
PLOT OF LOG OF MOMENTUM SPECTRUM OF HADRONS ESCAPING BACKOF CONFIGURATION
X BOUNDARIES: 0.0 TO 60.00 Y BOUNDARIES: -60.00 TO 60.00 (IN CM)
EXCLUDING PREVIOUS X,Y REGION (EXCEPT FOR CENTRAL REGION)
UNITS OF PTCLES/CM2*INC.PTCLE

LOG10 OF MOMENTUM SPECTRUM OF INTERACTING HADRONS




THE SYMBOLS *,2,3,4 REFER TO PROTONS,NEUTRONS,PI PLUS,PI MINUS
LOG10 OF MOMENTUM VALUES REFER TO AVERAGE OF EACH MOMENTUM BIN